PROCEEDINGS OF SCIENCE

D^* polarization as a probe to discriminate new physics in $\bar{B} \to D^* \tau \bar{\nu}$

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We study methods of distinguishing the new physics operators which provide a good fit to the excess measured value of R_{D^*}. Among the angular observables, we find that the D^* polarization fraction $f_L(q^2)$ is a good discriminant of scalar and tensor new physics operators. The change in $\langle f_L(q^2) \rangle$, induced by scalar and tensor operators, is about three times larger than the expected uncertainty in the upcoming Belle measurement.

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1. Motivation

The measurment of $R_{D^*}=\Gamma(B\to D^*\tau\bar{\nu})/\Gamma(B\to D^*l\bar{\nu})$, where $(l=e,\mu)$ by BaBar [1], Belle [2] and LHCb [3] experiments indicate the evidence for lepton flavour non-universality. The quark level transition $b\to c\tau\bar{\nu}$, which induces the decay $B\to D^*\tau\bar{\nu}$ occurs at tree level in the Standard Model (SM). Hence large new physics (NP) contributions are required to explain the excess value of R_{D^*}.

The authors of ref. [4] considered all the possible four-fermion operators which can lead to $B\to D^*\tau\bar{\nu}$. They parametrized them in the form

$$H_{\rm eff}=\frac{4G_F}{\sqrt{2}}V_{cb}\left[O_{V_L}+\frac{\sqrt{2}}{4G_FV_{cb}}\frac{1}{\Lambda^2}\left\{\sum_i\left(C_iO_i+C_i^{'}O_i^{'}+C_i^{''}O_i^{''}\right)\right\}\right],$$

where Λ, the scale of NP, is assumed to be 1 TeV. In the above $H_{\rm eff}$, the operator O_{V_L} is the SM operator responsible for the quark level transition $b\to c\tau\nu_\tau$. It has the usual $(V-A)*(V-A)$ structure. The other operators O_i, $O_i^{'}$ and $O_i^{''}$ have, in general all other possible Lorentz structures. In general, they can be of three types: products of vectors/axial-vectors, products of scalar/pseudo-scalars or products of tensors. Unprimed operators couple a quark bilinear to a lepton bilinear. Primed operators couple a bilinear of form $\bar{\tau}\Gamma b$ to the bilinear $\bar{c}\Gamma\nu$. Double primed operators couple a bilinear of form $\bar{\tau}\Gamma c^c$ to $\bar{b}^c\Gamma\nu$. The primed and double primed operators arise from leptoquark models. Each of them is related to corresponding unprimed operators through Fierz Transforms.

A fit to the data is done in ref. [4] under the following assumptions:

- Only one NP operator was considered at a time.
- two similar NP operators, such as vector + axial-vector or scalar + pseudo-scalar, were considered at a time.

Under these assumptions, they obtained values of different NP couplings which account for the excess R_{D^*} [4]. The question then becomes: How to distiguish between different NP solutions?

2. Analysis

Analysis of angular distributions in $B\to K^*(\to K\pi)l^+l^-$ has been developed as a standard tool to search for NP. We apply the same technique to $B\to D^*\tau\nu_\tau$. In the rest frame of $D^*(\to D\pi)$, one can define three angles:

1. θ_τ, which is the angle between p_B and p_τ,
2. θ_D, which is the angle between p_B and p_D,
3. ϕ, which is the angle between the two planes defined by the momenta of $\tau-\nu_\tau$ and $D-\pi$.

Since the τ momentum is difficult to reconstruct, measuring the distribution in θ_τ and in ϕ is hard. But it is possible to look at the distribution in θ_D.

The angular distribution in θ_D is given by

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_D} = \frac{1}{4}\frac{d\Gamma}{dq^2}\left[2 f_L(q^2)\cos^2\theta_D + \{1 - f_L(q^2)\}\sin^2\theta_D\right],$$

where

$$f_L(q^2) = \frac{A_L(q^2)}{A_L(q^2) + A_T(q^2)},$$

is called the D^* polarization fraction. $A_L(q^2)$ and $A_T(q^2)$ are the amplitudes for the D^* meson to have longitudinal and transverse polarizations respectively.

3. Results

We computed $f_L(q^2)$ and also $\langle f_L(q^2)\rangle$, for all the allowed NP couplings given in [4]. In the cases where the NP operators or their Fierz transformed forms have the same structure as the SM operators (O_{V_L}), the plots for $f_L(q^2)$ are identical to those of the SM. But for the cases, where the NP couplings are of scalar or tensor form, both $f_L(q^2)$ as well as $\langle f_L(q^2)\rangle$ differ substantially from the SM values. The NP couplings and the corresponding $\langle f_L(q^2)\rangle$ values are listed in Table 1.

Coefficient(s)	Best fit value(s)	$\langle f_L(q^2)\rangle$
C_{V_L}	-2.88 ± 0.04	0.46 ± 0.03
C_T	$0.52 \pm 0.02,$	0.16 ± 0.03
(C_{S_L}, C_{S_R})	$(3.08, -2.84)$	0.76 ± 0.03

Table 1: The values of NP coefficients for which $\langle f_L(q^2)\rangle$ differs significantly from the SM value.

In figure 1, we have plotted the variation of $f_L(q^2)$ with q^2 for the tensor NP couplings C_T and for scalar-psuedoscalar NP couplings $C_{S_L} - C_{S_R}$ [5].

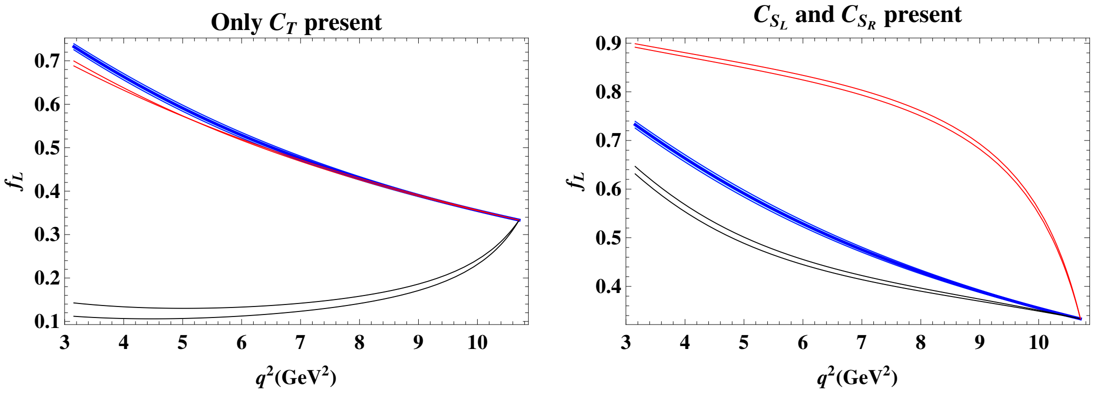

Figure 1: Plots of D^* longitudinal polarization fraction $f_L(q^2)$ as a function of the dilepton invariant mass q^2 in the decay $\bar{B} \to D^* \tau \bar{\nu}$. The blue band in the plots corresponds to the SM prediction. The band is due to theoretical uncertainties, mainly due to form factors, added in quadrature. The plots in the left panel represent $f_L(q^2)$ prediction in the presence of NP couplings $C_T = (0.52 \pm 0.02)$ (black) and $C_T = (-0.07 \pm 0.02)$ (red). The plots in the right panel correspond to NP coefficients $(C_{S_L}, C_{S_R}) = (-1.02, 1.25)$ (black) and $(3.08, -2.84)$ (red).

4. Conclusions

We find that the D^* polarization fraction is a good discriminant to distinguish different types of NP solutions to explain the R_{D^*} puzzle. The differences caused by the tensor and scalar NP solutions in $\langle f_L(q^2) \rangle$ is about three times of the expected uncertainty in the forth coming measurement of this quantity [6]. Therefore such a measurement is eagerly expected.

References

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